12-2010

Evaluate experiences necessary to achieve proficiency in advanced fiberoptic intubation skills : can we accelerate the learning curve with simulator training?

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EVALUATE EXPERIENCES NECESSARY TO ACHIEVE PROFICIENCY IN ADVANCED FIBEROPTIC INTUBATION SKILLS --- CAN WE ACCELERATE THE LEARNING CURVE WITH SIMULATOR TRAINING?

By

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A Thesis
Submitted to the Faculty of the
Department of Bioinformatics and Biostatistics, School of Public Health and Information Science, University of Louisville in Partial Fulfillment of the Requirements for the Degree of

Master of Science

School of Public Health and Information Science, University of Louisville, Louisville, Kentucky

December 2010

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A Thesis Approved on

December 1st, 2010

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ACKNOWLEDGEMENTS

My deepest gratitude goes first and foremost to Professor Dongfeng Wu, my supervisor, for her constant encouragement and guidance. She has walked me through all the stages of the writing of this thesis. Without her consistent and illuminating instruction, this thesis could not have reached its present form. Second, I would like to express my heartfelt gratitude to Professor Rana K Latif, one of my committee members, and his group for collaboration in data collection; and thanks Professor John Allen Myers, also one of my committee members, who have instructed and helped me a lot in the past three years.

Last my thanks would go to my beloved family for their loving considerations and great confidence in me all through these years. I also owe my sincere gratitude to my friends and my fellow classmates who gave me their help and time in listening to me and helping me work out my problems during the difficult course of the thesis.

ABSTRACT

EVALUATE EXPERIENCES NECESSARY TO ACHIEVE PROFICIENCY IN ADVANCED FIBEROPTIC INTUBATION SKILLS ---CAN WE ACCELERATE THE LEARNING CURVE WITH SIMULATOR TRAINING?

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Fiberoptic intubation skills (FOI) are critical in reducing the anesthesia related morbidity and mortality in clinical settings. The purpose of the study was to prove that the simulator can train a novice to achieve the expert level in a relatively short time. The performance of the pre- and post-training of novice group and expert group was computer or video recorded. Three statistical methods were applied for data analysis. The number of airway collisions and the number of passes for oral and nasal were analyzed by a newly proposed maximum likelihood method. The development of this model is based on the assumption that the data follows a Poisson distribution. The total time to complete the procedure, the time to pass the oral and nasal, the time to train and re-train the novice group were analyzed by t-test and paired t-test. The questionnaire score and Pass/Fail score of both groups were analyzed by z-test. The results showed that the novice could reach the expert level after training.

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1. INTRODUCTION

Fiberoptic inctbation skills are important since the management of a difficult airway remains the most common cause of anesthesia related death [1]. Providing sufficient training in FOI, particularly hands-on experience in anesthetized patients, has always been difficult [2-4] mainly because of technical and ethical problems [5, 6]. Recent surveys from different countries have revealed that the prevalence of sufficient fiberoptic intubation skills among anesthesiologist is still low [7-10].

The purpose of this study was to prove that the simulator can train a novice to achieve the expert level in a relatively short time. Two simulators were involved in the study. The computerized Accu Touch Bronchoscopy Simulator (ATBS, Immersion Medical, Gaithersburg, MD) (Appendiex A) was used in this study for teaching, training and fiberoptic skills evaluation. And the Non-Electronic Human Anatomy Airway Simulator (NEHAAS, Medical Plastic Laboratory) (Appendiex B) was used for FOI skills evaluation also. Data related to the performance on the bronchoscopy are recorded by the computer. The performance on NEHAAS was video recorded. Medical students participating in the study were referred to as novice; certified resisted nurse anesthetist (CRNA) or faculty were referred to as expert. After training, if the novice did not actively maintain the repetitive practice, skill level would decay. The retention of fiberoptic intubation skills was tested on the novice group 2 months later for a post training session by performing one fiberoptic endoscopy on ATBS. The data were recorded and 3 different statistical models were used to analyze the difference between the novice group (before and after training) and the expert group, the improvement of the novice group after training and the skills decay over time.

ATBS can display computer-generated realistic anatomical images and record the data that are related to the performance of the bronchoscopy, such as the number of contacts with the mucous membranes (also called airway collusion), the number of attempts needed to pass through the glottis, the time in red-out, the time in hypopharynx, the time to pass nasal, the time in Nasopharynx, the time in Oropharynx, the time to pass oral, and the total time of the procedure.

NEHAAS consists of a head, a neck and an upper chest. Inside the mouth there are a simulated pharynx and a larynx which leads to a simulated trachea and airway. The device is not electronic or computerized. Two blinded faculty rated video clips, and gave binary score for eleven items in scoring checklist (Appendix C) with Pass = 1 (no further training) and Fail = 0 (more training required). A final Pass/Fail score was gave for each novice and expert according to the overall performance.

2. MATERIALS AND METHODS

2.1 Novice Group and Expert Group

Eight anesthesiologists who have performed more than 100 fiberoptic intubations were recruited as the expert group. The performance of experts on ATBS and NEHAAS was computer recorded or video recorded and used as the "expert standard".

Fifteen fourth year medical students with no previous experience of FOI were recruited as the novices group. They received a 15 minutes long simulation-based training. The performance of the novice group (before and after training) on both simulators was recorded. The total time needed and total attempts need to achieve the successful FOI were also recorded.

Two months after the training, twelve novices out of fifteen were tested on the FOI dexterity decay. Their performance on the simulator before and after retraining was recorded. The attempts and times needed to be trained back to the expert level were also recorded for the skill decay study.

All study was done in University of Louisville Hospital, Louisville, Kentucky.

2.2 Data Analysis Methods

2.2.1 Developed Maximum likelihood method

For discrete data, such as number of airway collisions and the number of passes for oral and nasal, a testing procedure based on likelihood ratio was derived to analyze the difference between different groups and the change of skill in novice group over time. This derived test was based on the assumption that the number of airway collision follows a Poisson distribution.

We use a random variable X represent the number of airway collisions in expert group for each person and a random variable Y represent this number in novice group for each person. The likelihood function is: $L(\lambda | X) = \prod_{i=1}^{n} \frac{e^{-\lambda} \lambda^{xi}}{Xi!}$, therefore, we get the Maximum Likelihood Estimates: $\lambda_1 = \frac{1}{n} \sum_{i=1}^{n} Xi$ (for expert group) and $\lambda_2 = \frac{1}{m} \sum_{i=1}^{m} Yi$ (for novice group).

The sample size of the expert group and the novice group were n and m respectively, so $\sum_{i=1}^{n} Xi$ follows a Poisson distribution with mean = $n\lambda_1$ and $\sum_{i=1}^{m} Yi$ follows a Poisson distribution with mean = $m\lambda_2$.

To compare the number of contacts with the mucous membranes (or the number of oral and nasal passes) in expert group and the novice group, we are actually comparing theλ_1 andλ_2. So the null hypothesis and the alternative hypothesis will be:

H_0: $\lambda_1 = \lambda_2$

H_a: $\lambda_1 \neq \lambda_2$ or H_a: $\lambda_1 > \lambda_2$

If we let $\lambda = \lambda_1$ and$\Phi = \frac{\lambda 2}{\lambda 1}$, the hypothesis will be transformed to:

H_0: $\Phi = 1$

H_a: $\Phi \neq 1$ or H_a: $\Phi > 1$

Then variable X will be transformed to X follows a Poisson distribution with parameter λ and Y follows a Poisson distribution with parameter $\lambda\Phi$ accordingly. If we let $S_x = \sum_{i=1}^{n} Xi$ and $S_Y = \sum_{i=1}^{m} Yi$, we get $S_0 = S_X + S_Y$ follow a Poisson distribution with parameter $n\lambda + m\lambda\Phi$, and the joint Probability Mass Function will be:

$$P\,(S_X = S_1,\, S_Y = S_2 | S_0 = S_0,\, \lambda,\, \Phi) = \frac{P(SX=S1,\ SY=S2|\lambda,\Phi)}{P(\,S0=S0|\lambda,\Phi)}$$

$$= \binom{S0}{S2}\left(\frac{n}{n+m\Phi}\right)^{S1}\left(\frac{m\Phi}{n+m\Phi}\right)^{S2}$$

So, we get that conditional distribution of S_Y given S_0 follows a binomial distribution with parameters (S_0, $p = \frac{m\Phi}{n+m\Phi}$), and the hypothesis was transformed to:

H_0: $p = \frac{m}{m+n}$ (if $\Phi = 1$)

H_a: $p \neq \frac{m}{m+n}$ (if $\Phi > 1$) or H_a: $p > \frac{m}{m+n}$ (if $\Phi > 1$)

To compare the novice group pre-training vs post-training performance, the corresponding p-value will be:

$$\text{p-value} = P\left(S_Y \geq s_Y \mid S_X + S_Y = S_0, \Phi = 1\right)$$

$$= P\left(S_Y \geq s_Y \mid p = \frac{m}{m+n}\right)$$

$$= \sum_{K=SY}^{S0} \binom{S0}{K} (p)^k (1-p)^{S0-k}$$

To compare the novice group post-training vs expert group performance, the corresponding p-value will be:

$$\text{p-value} = 2*P\left(Z \geq |z|\right) = 2* \frac{SY-p}{\sqrt{S0pq}}$$

2.2.2 Paired T-test and Two-Sample T-test

We assume the data related to time in both novice and expert group, like the total time to finish one FOI, the time in red-out, the time to pass nasal, the time to pass oral and the total time for novice to get trained/re-trained, follows a Normal distribution. Paired t-test and two-sample t-test were applied and the tests were performed using SAS.

Specifically, two-sample t-test was used to test the hypothesis that performance of the pre-training novice group ($n_1 = 15$) and the expert group ($n_2 = 8$) are different; similarly, a two-sample t-test was used to test the performance difference between the post-training novice group ($n_1 = 15$) and the expert group ($n_2 = 8$), the 2 month later pre-training novice group ($n_3 = 12$) and the pre-training novice group, the 2 month later pre-training novice group and the post-training novice group, the 2 month later pre-training novice group and the expert group, the 2 month later post-training novice group ($n_3 = 12$) and the pre-training novice group, the 2 month later post-training novice group and the post-training novice group, the 2 month later post-training novice group and the expert group; a paired t-test was used to compare the performance between the pre-training and post-training for the novices group with sample size $n_1 = 15$ and 2 month later pre-training and post-training for the novices group with sample size $n_2 = 12$.

For data from total attempts for novice to get trained/re-trained, we can approximately assume that the mean of these data follows a Normal distribution by applying the Central Limit Theorem (CLT). Hence, a two-sample t-test was used in testing the difference between training and re-training.

2.2.3 Proportion Z-Test

For data from the total checklist performance scores and Pass/Fail score, since it is listed as "Pass" and "Fail", it follows a Binomial distribution. A two-sample proportion z-test was used to carry out the testing procedure.

To compare the novice group post-training vs expert group performance, the corresponding p-value (2-tailed p-vale) will be:

p-value = 2 * P $(Z \geq |z|) = 2 * \frac{(p1-p2)}{\sqrt{p(1-p)(\frac{1}{n}+\frac{1}{m})}}$, while $p_1 = \frac{Sx}{n}$, $p_2 = \frac{Sy}{m}$ and $p = \frac{S0}{m+n}$.

To compare the novice group pre-training vs post-training performance, the corresponding p-value (one tailed p-value) will be:

p-value = P $(Z > z) = \frac{(p1-p2)}{\sqrt{p(1-p)(\frac{1}{n}+\frac{1}{m})}}$

3. RESULTS AND DISCUSSION

We plug in the experimental data from the University of Louisville Hospital and analysis the results. The data we analyze here includes: the number of airway collision, the number of oral and nasal passage, the total time to finish the FOI, the total time used and total attempts used to train the novice, the checklist score, the Pass/Fail score, ect.

3.1 Developed Maximum likelihood method to analysis the improvement of airway collision and oral, nasal passage skills

The developed maximum likelihood model provides a way to analysis the simulator training results in the hospital. For the airway collision, we compared the pre-training and after training performance of the novice, and also we compared the performance of the novice and the expert. Before training, the number of airway collision in the novice group is significantly more than the expert group (p-value < 0.0001), but their performance can be significantly improved after training session (p-value <0.0001, novice before-training vs novice post-training) and can reach the expert level (p-value = 0.1709, novice post-training vs expert) (Fig 1, Table 1). However, the skills of novice get significantly decayed after 2 months (p-value <

0.0001, novice post-training vs novice 2 month later pre-training), but still obviously better than their pre-training performance (p-value < 0.0001, novice pre-training vs novice 2 month later pre-training). Data also shows that although the skills could decay over time, the trained novice can easily get trained back to the expert level compare to before training novice.

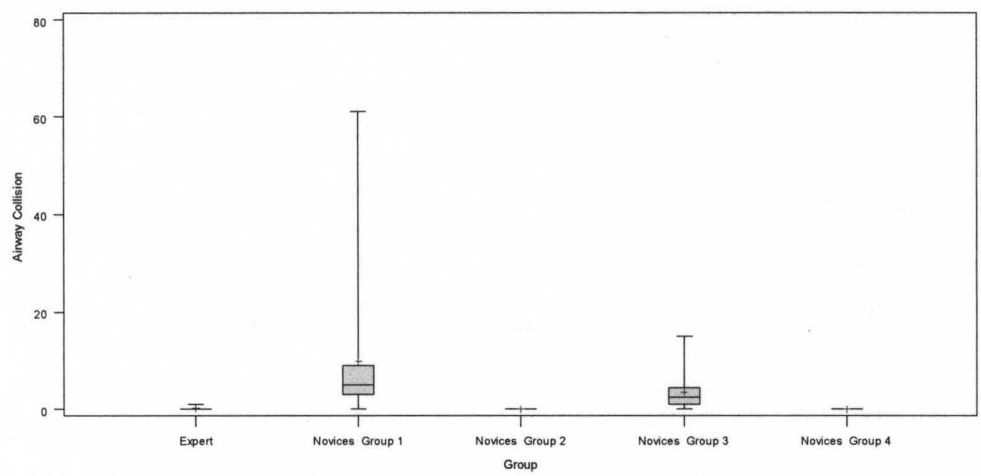


Figure 1. The box-plot of the number of airway collision in each group (with 95% confidence interval). Novice Group1: Novice group before training; Novice Group 2: Novice group after training; Novice Group 3: Novice group 2-month later before training; Novice Group 4: Novice group 2-month later after training.

(A)

	Novice		Novice (2 Month Later)	
	Pre-Training	After Training	Pre-Training	After Training
Expert	<0.0001	0.1709	<0.0001	0.414

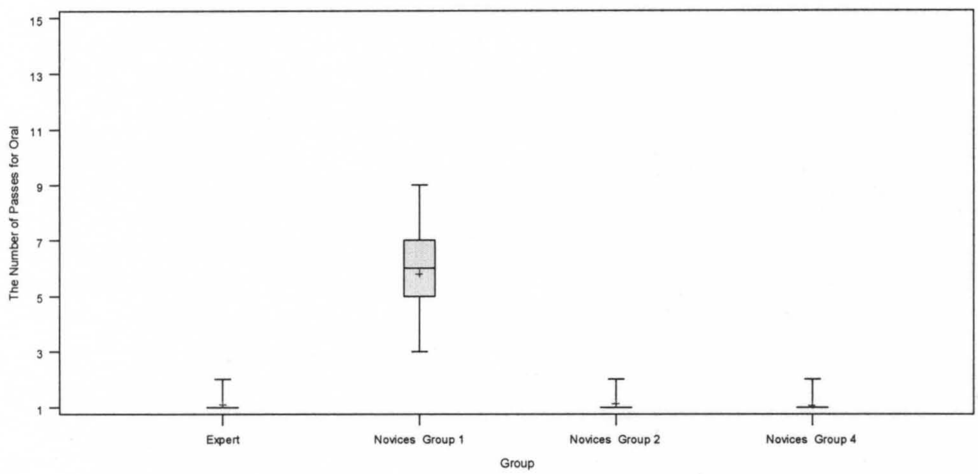
(B)

Novice (2 Month Later)	Novice	
	Pre-Training	After Training
Pre-Training	<0.0001	<0.0001
After Training	<0.0001	Close to 1

Table 1. Comparison of the number of collision with airway in novice group and expert group

The Fiberoptic bronchscopy results show that, the number of passes for oral and nasal in pre-training novice group is significantly more than the expert group (p-value < 0.0001, novice pre-training vs expert for oral passage skills; p-value < 0.0001, novice pre-training vs expert for nasal passage skills) (Figure 2 A, 2 B, Table 2). The skills of oral passage in novice group can be trained to the expert level (P-value < 0.0001, novice post-training vs expert) and be very well maintained after re-trained (P-value < 0.0001, novice 2 month post-training vs expert). The skills of nasal passage in novice group can be significantly improved after training (p-value < 0.0001, novice pre-training vs novice post-training) and reach expert level (p-value = 0.5014, novice post-training vs expert). After re-trained, nasal passage skills can be further improved, though not significant (p-value = 0.2829, novice post-training vs novice 2 month post training).

(A)



(B)

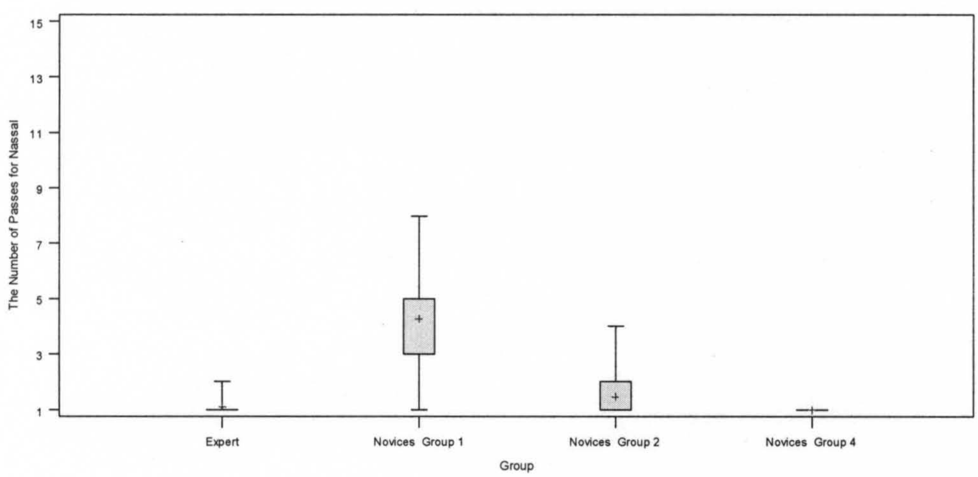


Figure 2. The box-plot of the number of passes for oral (A) and nasal (B) in each group (with 95% confidence interval). Novice Group1: Novice group before training; Novice Group 2: Novice group after training; Novice Group 4: Novice group 2-month later after training.

	Pre Training/ Post Training	Pre Training/ Expert	Post Training/ Expert	2 Month Post Training# / Post Training	2 Month Post Training# / Expert
Oral*	<0.0001	<0.0001	0.9857	0.9025	0.9306
Nasal*	<0.0001	<0.0001	0.5014	0.2829	0.7893

Table 2. Comparison of the number of passes for oral and nasal in novice group and expert group.
*: The number of passes
#: 2 Month post training means the performance of novice group after re-trained 2 month later.

3.2 Paired T-test and Two-Sample T-test

The expert group use significantly less total-time to successfully finish the task on the Fiberoptic Bronchscopy (P-value = 0.0004), when compared with the novice pre-training group. After the training session, the novice group can perform as good as the expert group (p-value = 0.5242). The POI skills' decay over the time is obviously. After 2 month, the novice group use significantly more time to finish the task comparing to after training stage (p-value = 0.0118), but still much better than the pre-training stage (p-value = 0.0138) (Figure 3, Table 3). They can re-gain the skills to expert level (p-value = 0.5863) with less training time comparing to the first time training session.

We compared the total time and total attempts needed to train and re-train (2 months later) the novice group to reach the expert level. The total time needed for re-training the novice is significantly less than the first time training process (p-value = 0.0288). And the attempts are less but not significant (p-value = 0.1715) (Figure 4).

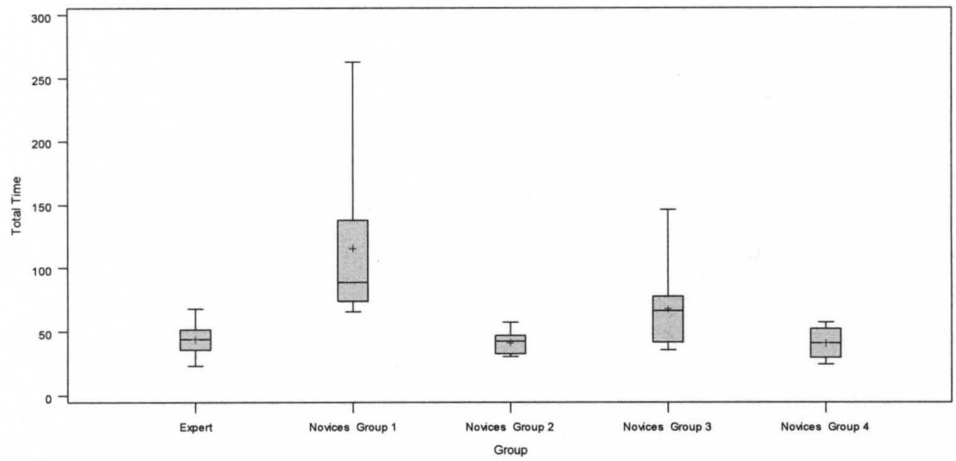


Figure 3. The box-plot of the total time used to finish FOI in novice group and expert group (with 95% confidence interval). Novice Group1: Novice group before training; Novice Group 2: Novice group after training; Novice Group 3: Novice group 2-month later before training; Novice Group 4: Novice group 2-month later after training.

(A)

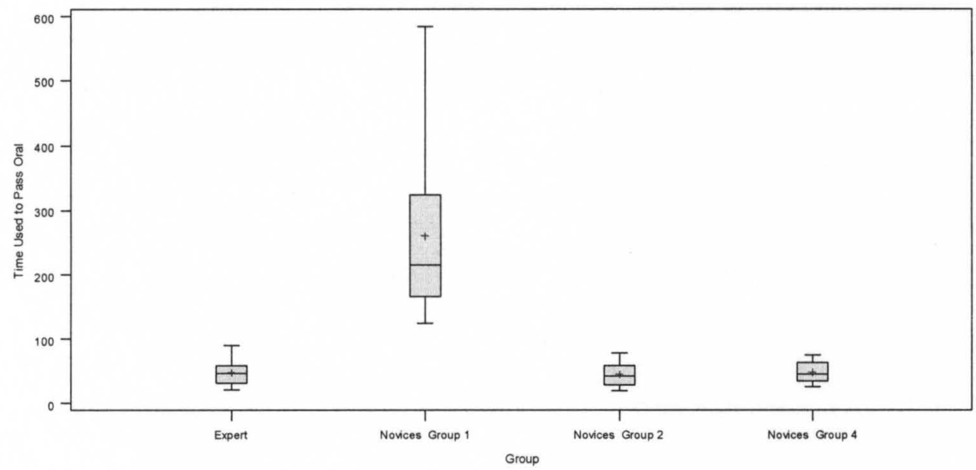
	Novice		Novice (2 Month Later)	
	Pre-Training	After Training	Pre-Training	After Training
Expert	0.0004	0.5242	0.0302	0.5863

(B)

	Novice	
Novice (2 Month Later)	Pre-Training	After Training
Pre-Training	0.0138	0.0118
After Training	0.0002	0.9385

Table 3. Comparison of the total time used to finish FOI in novice group and expert group

(A)



(B)

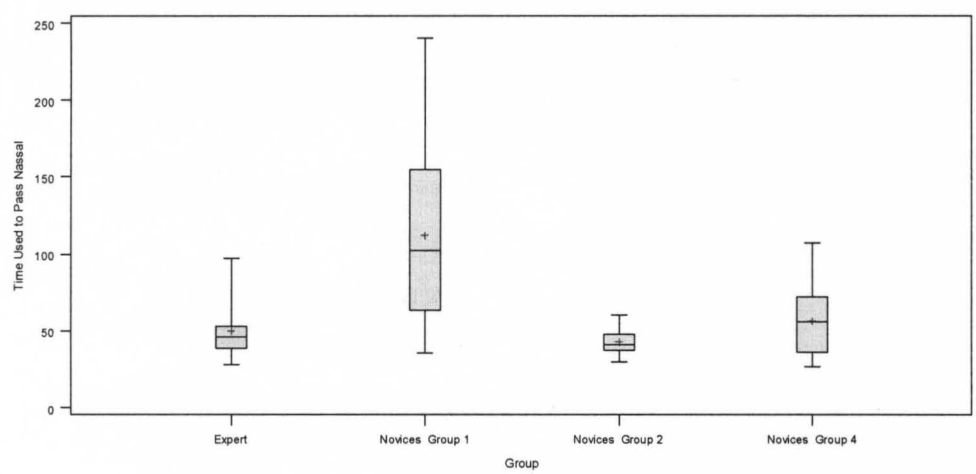


Figure 4. The box-plot of the time used to pass oral (A) and nasal (B) in novice and expert group (with 95% confidence interval). Novice Group1: Novice group before training; Novice Group 2: Novice group after training; Novice Group 4: Novice group 2-month later after training.

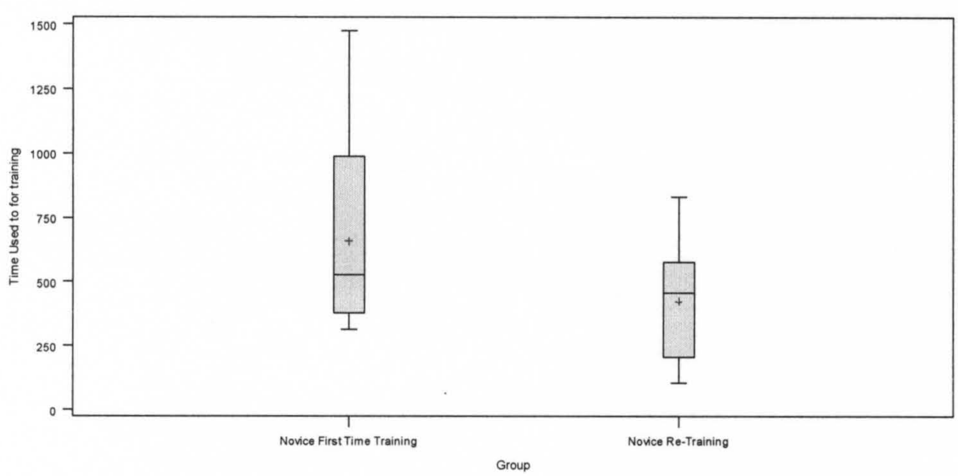
The oral time and nasal time (speed) in these groups follow the same pattern as well (Figure 5, Table 4). The time used for passing the oral and nasal get significant shortened after training (p-value < 0.0001 for oral and p-value = 0.0004 for nasal), and reached the expert level (p-value = 0.6782 for oral and p-value = 0.3969 for nasal). The skills can be maintained after re-training.

All these show that after the simulator training, the novice group will use significantly less time to finish the oral passage and nasal passage procedures, and use significantly less time to finish the whole process of FOI, and reach the expert level.

	Pre Training/ Post Training	Pre Training/ Expert	Post Training/ Expert	2 Month later / Post Training	2 Month later /Expert
Oral (S)	<0.0001	<0.0001	0.6782	0.6782	0.9322
Nasal (S)	0.0004	0.0015	0.3969	0.0902	0.5394

Table 4. Comparison of the time used to pass oral and nasal in novice group and expert group

(A)



(B)

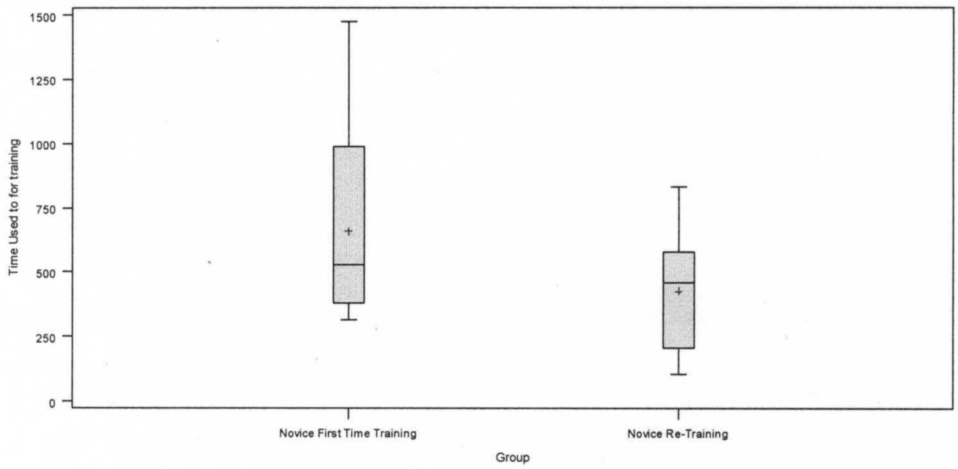


Figure 5. The box-plot of the time (A) and attempts (B) needed to train and retrain the novice to reach expert level (with 95% confidence interval)

3.3 Proportion Z-Test

The performance of expert and novice about oral and nasal fiberoptic intubation on HAAS was video recorded. The skills were scored by two independent blinded faculty raters according the checklist (Appendix C). (0, 1) was used to indicate Pass/Fail for each step in the checklist and a final Pass/Fail was given in the end. To reduce the bias, we merged the two professors' scoring results.

	Expert	Pre Training	Post Training	2 Month Post Training
1	1.00±0.00	0.37±0.49	0.97±0.18	1.00±0.00
2	1.00±0.00	0.10±0.31	0.97±0.18	1.00±0.00
3	1.00±0.00	0.53±0.51	1.00±0.00	1.00±0.00
4	1.00±0.00	0.33±0.48	1.00±0.00	0.96±0.20
5	0.88±0.34	0.33±0.48	0.97±0.18	1.00±0.00
6	0.75±0.44	0.17±0.38	0.97±0.18	0.96±0.20
7	0.88±0.34	0.07±0.25	1.00±0.00	1.00±0.00
8	0.88±0.34	0.33±0.48	0.97±0.18	1.00±0.00
9	0.88±0.34	0.10±0.31	0.93±0.25	1.00±0.00
10	0.75±0.44	0.20±0.41	1.00±0.00	1.00±0.00
11	0.88±0.34	0.30±0.47	1.00±0.00	1.00±0.00
F/P	0.88±0.34	0.27±0.45	1.00±0.00	1.00±0.00
Total Score	9.88±2.33	2.83±2.64	10.77±0.63	10.92±0.28

Table 5. Te scores of novice group and expert group (with 95% confidence interval)

"Pass" and "Fail" follow a Binomial distribution. A two-sample proportion z-test was used to analysis the results. All eleven scores from checklist are significantly improved for the post-training novices group compared with their own pre-training performance (all p-value < 0.0001) (Table 5, 6). The post-training group in all areas performed at least at the same level or even better when compared with the expert group. Specifically, for question 6, 7, 10, 11, they can perform better than expert group, though not significantly. After two months passed and re-trained, the novice's skills in all eleven areas have remained the same or get further improved. The total score and Pass/Fail score of the novice group and expert group follows the same pattern as the checklist score (Table 5).

	Pre Training/ Post Training	Pre Training/ Expert	Post Training/ Expert	2 Month/ Pre Training	2 Month/ Post Training	2 Month/ Expert
1	<0.0001	<0.0001	0.46	<0.0001	0.37	~1
2	<0.0001	<0.0001	0.46	<0.0001	0.37	~1
3	<0.0001	0.0005	<0.0001	<0.0001	~1	~1
4	<0.0001	<0.0001	<0.0001	<0.0001	0.26	0.41
5	<0.0001	0.0002	0.23	<0.0001	0.37	0.076
6	<0.0001	<0.0001	0.024	<0.0001	0.82	0.051
7	<0.0001	<0.0001	0.048	<0.0001	~1	0.076
8	<0.0001	0.0002	0.23	<0.0001	0.37	0.076
9	<0.0001	<0.0001	0.50	<0.0001	0.20	0.076
10	<0.0001	0.0001	0.042	<0.0001	~1	0.01
11	<0.0001	0.0001	0.048	<0.0001	~1	0.076
F/P	<0.0001	<0.0001	0.048	<0.0001	~1	0.076
Total Score	<0.0001	<0.0001	0.23	<0.0001	0.68	0.16

Table 6. Comparison of the checklist score, total score and Pass/Fail score in novice group and expert group

4. CONCLUSIONS

Three statistical models were used in this study: 1). Derived maximum likelihood method, 2). Paired T-test and Two-Sample T-test method, 3). Z-test method to analysis different distributed data generated during the simulator training for FOI skills. All the results show that the novice group can reach the expert level or even better than the expert level. The skills show different levels of decay with time, but the novice can be re-trained with less time comparing to the first time training process. We proved that the simulator can train a novice to achieve the expert level for FOI skills in a significantly shorter time. This has significant meanings in improving fiberoptic intubation skills among anesthesiologist and decreasing the anesthesia related morbidity and mortality in clinical settings.

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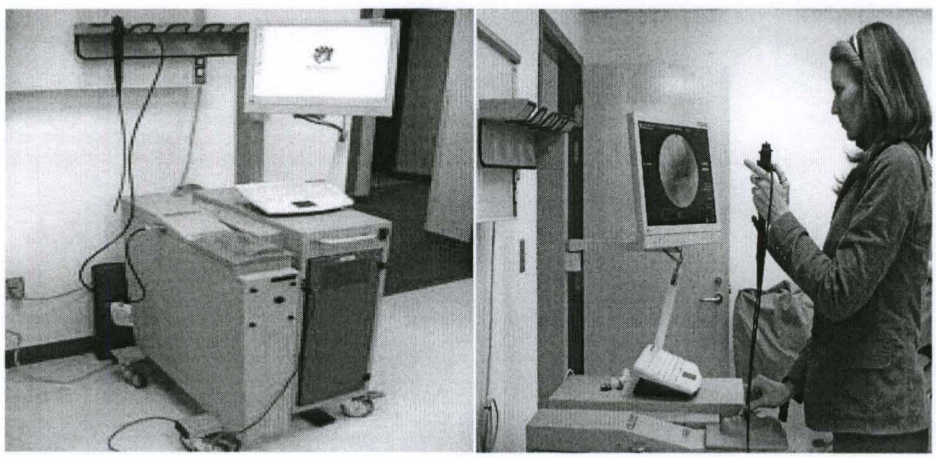
APPENDIX A

The computerized Accu Touch Bronchoscopy Simulator (ATBS, Immersion Medical, Gaithersburg, MD)

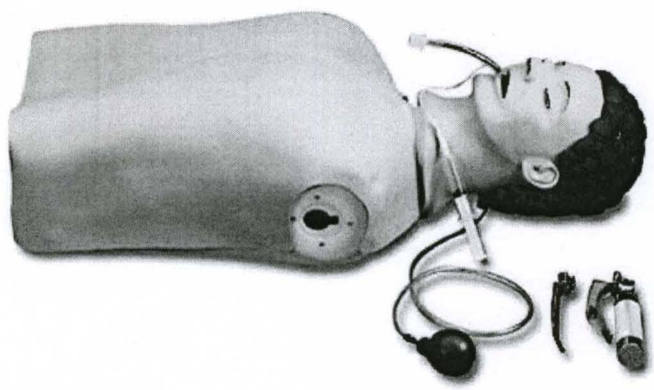


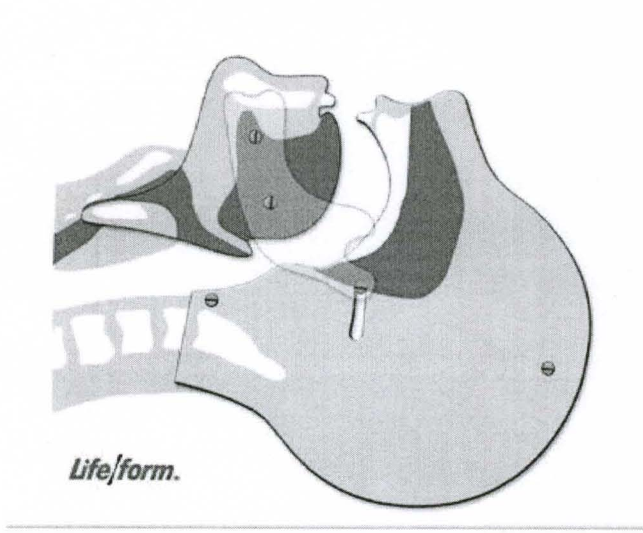
Key Features:

- Force feedback integrated with audio and visual feedback responses
- Hemodynamic profile reflective with patient monitor in response to treatment
- Objective learner evaluation capabilities through measurable outcomes and metrics

APPENDIX B

Non-Electronic Human Anatomy Airway Simulator (NEHAAS, Medical Plastic Laboratory)





APPENDIX C

Checklist for Fiberoptic Intubation Performance

		Done Correctly	Done Incorrectly
1	Hold control section correctly in one hand with thumb position for flexion and extension control, and index finger for suction		
2	Focus scope using appropriate external object		
3	Control tip of scope with other hand		
4	Introduce bronchoscope into mouth/ nose centered		
5	Maneuvers bronchoscope through nasopharynx/ oropharynx and visualizes cords		
6	Passes cords		
7	Continues insertion of bronchoscope until visualization of carina		
8	Passes endotracheal tube atraumatically		
9	Reconfirm vision of carina after ETT *in situ*		
10	Removes bronchoscope smoothly		
11	Hold the fiberoptic scope firmly and straight		

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PUBLICATIONS

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